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PASSIVE SOLAR ENERGY FOR RESIDENTIAL SPACE HEATING

Prepared for

MONTANA DEPARTMENT of NATURAL RESOURCES and CONSERVATION

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Passive solar energy for residential spa
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PASSIVE SOLAR ENERGY FOR RESIDENTIAL SPACE HEATING

Prepared by

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December, 1980

Prepared for

Montana Department of Natural Resources and Conservation
32 South Ewing, Helena, Montana 59620
Renewable Energy and Conservation Program
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I. OBJECTIVE

The general purpose of this project is to demonstrate the feasibility of residential passive solar heat in a Western Montana site. The major design innovation is the integration of a wood burning furnace into a standard Trombe wall design. By using the solar thermal mass to store the furnace heat as well, it is hoped that the major disadvantages of wood-backup could be overcome. Infrequent but very hot firings of the furnace should result in reduced air pollution and should help avoid constant stoking of a fire.

II. PROJECT IMPLEMENTATION

1. Project Planning and Equipment Acquisition

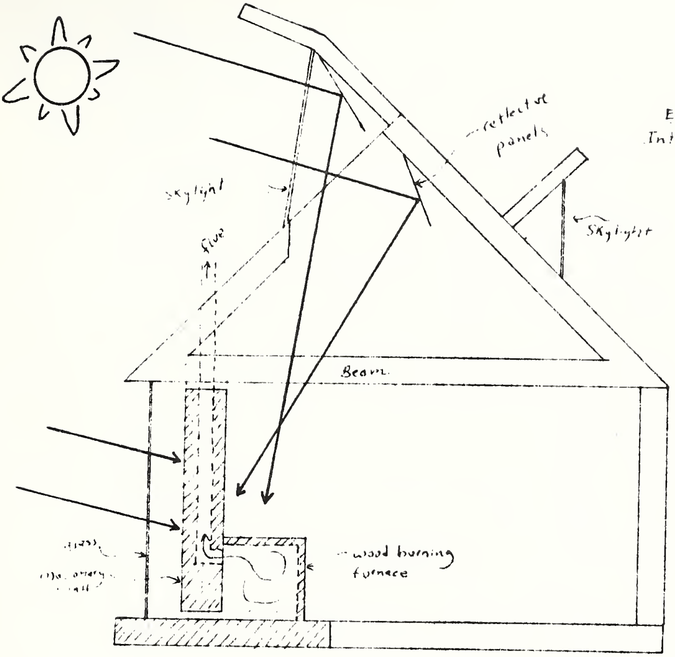
In order to plan for this project I did extensive research on my own. Major information sources were Solar Energy, Solar Age and Other Homes and Garbage. I lived in a tent near the site for a year preceding construction in order to familiarize myself with the site characteristics.

The heart of the energy system is a 36 feet long and 8 foot high Trombe wall resting on a 8 x 43 foot cement slab foundation. Sun shining through the glass wall on the South heats the wall and induces a connective current. (Exhibit 2). The wall is one foot thick at the top and two feet at the bottom to provide approximately 40 tons of thermal storage capacity, not counting the slab or furnace. My major design problem was a North slope location, which made it necessary to develop a substantial backup heat source. Since I had the site, my idea was to design a system that made efficient use of the resources I did have - fair sun and lots of wood. Since the site is at 4,700 feet,

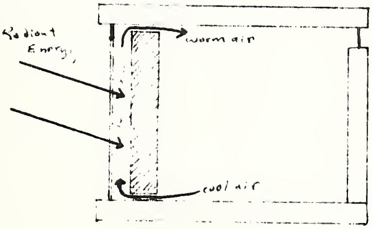
Exhibit 1

Integrated Wood and Solar System

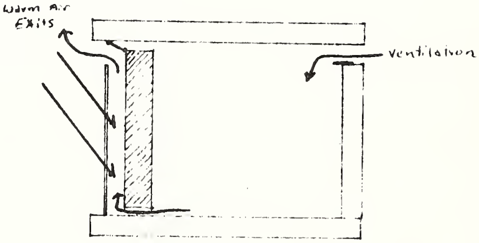
Scale: 1" = 5'



Schematic of the Trombe wall



Winter Operation



Summer Ventilation

and well above the inversion layer, I would not expect to aggravate air quality in the valley. The furnace is built into the West end of the wall with a flue that runs 25 feet through the wall and exits out a chimney on the East. (See Exhibit 2)

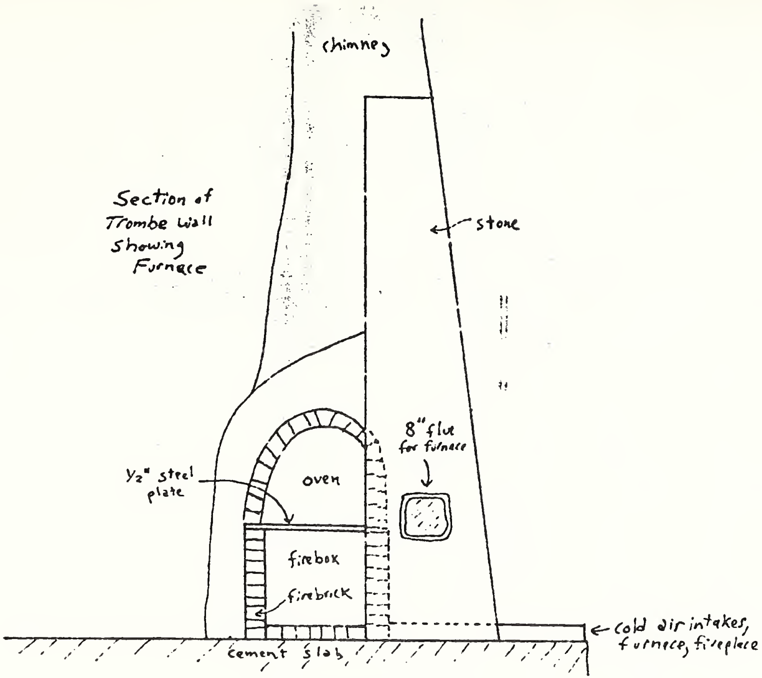
The only design parameters for the wall itself are surface area and volume. I used a rule of thumb suggested by Trombe: 1 square meter surface for 10 cubic meters of interior volume. For my initial design of 10,400 ft^3, this implies a 300 ft^2 wall. My finished wall is about 35 x 8 or 280 ft^2, and interior chimney surface adds at least 50 ft^2 on the South.

The volume or mass depends on storage requirements. I designed to store for three sunless days in January. The heat loss of the building is given in Exhibit 3. Three days in January amounts to about 1.3 million BTU with curtains closed. The heat capacity of rock is specific heat (.2) times density (174 lb/ft^3) or 34.8 BTU/ft^3-°F. Concrete is (.2) times, (135) or 27.0. My design provides for about 60 tons of interior stone (680 ft^3) and a 25 ton slab (378 ft^3) or a storage capacity of 33,870 BTU for every 1° F change in temperature. To meet a three day 1.3 million BTU heat load, the wall would have to cool 38° F. This suggests what seems to be a reasonable operating temperature range - such as 85° to 45°.

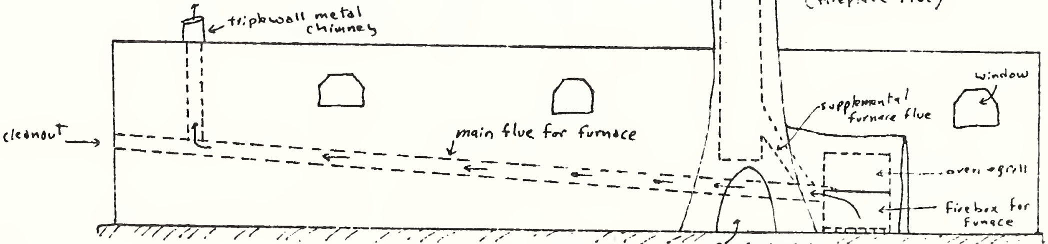
Given these dimensions, I calculated the solar heat the system would provide. I used a method developed by Doug Balcomb of the Los Alamos Scientific Laboratory ("A Simple Empirical Method for Estimating the Performance of a Passive Solar Heated Building of the Thermal Storage Wall Type", Proceedings of the 2nd National Passive Solar Conference.)

Exhibit 2

INTEGRATED WOOD-BURNING FURNACE, FIREPLACE, AND TROMBE WALL.



Section of Trombe Wall Showing Furnace



Interior View of Trombe Wall (scale: ⅓" = 1 ft)

EXHIBIT 3

HEATING LOAD

ITEM	Surface Area (ft^2)	r-factor		Heat Loss (BTU/°F-hr)	
		no insul.	insulation	no insul.	insulation
Roof	1763	2.06	40.06	855.8	44.0
Walls	1577	2.98	29.98	529.2	52.6
Windows					
South	480				
Tower South	60				
Other	151				
	691	1.81	11.81	381.8	58.5
Doors	120	2.0	11.0	60.0	10.9
Floor					
Slab	390	-	-	25.1	25.1
Deck	806	2.0	32.0	403	25.2
Infiltration	(19,740 ft^3)(½ Air Change) (.018)			177.7	177.7

SUMMARY

Case	BTU/DEGREE Day	Million BTU/year	BTU/DD-ft^2
No insulation	58,392	474.4	22.1
Insulation, no curtains	17,208	139.8	6.5
Insulation, Curtains	9,456	76.8	3.6

(for 8125 Degree Days/year in Missoula; 2640 ft^2 possible floor area)

The analysis is summarized in Exhibit 4. The monthly load is based on Exhibit 3, except that Balcomb suggests an average R factor of 8.3 for the South glazing with R-9 insulation open between 8:00 a.m. and 5 p.m. The horizontal radiation is derived from the weather bureau's 25 year history of hours of sunlight for Missoula. CharlessFowlkes' 1978 data (corrected to the horizontal) for Missoula happens to vary from this by about 5% (Montana Solar Data Manual). Balcomb's method relies on an apparently stable exponential relationship across sites between the solar heating fraction (% solar heat provided) and the solar load ratio (absorbed radiation over heating load). Parameters for various systems are in his paper.

The absorbed radiation in Exhibit 4 shows zero sunlight in December and January due to my severe North slope location. In addition I get about 69% of February sun and 80% of November sun (about 10 a.m. to 2 p.m.). However, in total the site difficulties only reduce my useful solar energy about 25% from the maximum possible. This is because the December and January sun is very limited in the first place in Missoula (about 27% sunlight) and because most sunlight is absorbed on a fixed South surface when the rays are nearly perpendicular between 10 a.m. and 2 p.m. (about 75%. Snow reflection is included in the calculations (a factor of 1.3 in February, 1.4 in March, and 1.2 in November - based on Balcomb's method). Using this analysis I expect to get about 51% of my heat from the sun, even in my difficult location. Because of the high level of insulation in the building, the remaining heat load is onlv 40 million BTU and should be met by burning three to four cords of wood per year. My 49 acre site of larch-doug fir habitat will yield 40 to

EXHIBIT 4

HEAT PROVIDED BY PASSIVE SYSTEM

Month	Missoula Degree Days	Monthly Load (M BTU	Horizontal Radiation BTU/ft^{2}month	Absorbed Radiation on Verticle (M BTU)	Solar Load Rate Ratio	Solar Heating Fraction	Auxiliary Energy (M BTU)
January	1420	14.1	11569	0	0	o	14.1
February	1120	11.1	14835	9.0	.81	.55	5.0
March	970	9.6	28507	18.9	1.97	.87	1.2
April	621	6.2	38435	11.9	1.92	.87	.8
May	391	3.9	52670	11.4	2.92	.96	.2
June	219	2.2	56082	10.4	4.73	1.00	0
July	34	.3	72463	14.1	47.00	1.00	0
August	74	.7	53818	13.9	19.86	1.00	0
September	303	3.0	43271	16.6	5.53	1.00	0
October	651	6.5	26077	15.0	2.31	.92	.5
November	1035	10.3	11619	8.4	.82	.55	4.6
December	1287	12.8	6349	0	0	0	12.8
TOTAL	8125	80.5				.51	39.2

70 ft^3/acre or 25 to 35 cords/yr. I hope to do better than 51% by using the insulating curtains continuously in the dark months, not heating the entire place except as used (thermal zones). I also suspect that sunlight availability is considerably better than in the inversion-prone valley. Data gathered by Ron Erickson in 1975, 76, and 77 suggests that we may average 52% sunlight in the canyon over a 7 month heating season as opposed to 39% in town (or one-third more sun). Also my heat load may be lower by living in the thermal belt halfway up a mountain and out of the inversion. For example, on the 29th of January in 1976 it was 45° F at Erickson's at 9:00 p.m., but 33.6° F at a station at 323 Hazel Street. I am clearing the slope above my place to leave a few larch (good solar trees that shed their needles and give fall color) and plant it to a good low-growing apple/huckleberry orchard.

2. System Installation

Only two system components were not site-built. Jeff Kooris of Missoula built the 3' x 6' collector for domestic hot water. Culbertson's Steel of Missoula custom-built the top plate for the wood-burning furnace. These were completed in the summer of 1977. On site construction began when the slab was poured in August of that year. Stone for the wall and chimney was also picked and hauled from nearby slopes that month.

The stone work was begun in late September. The masons were Barry Chandler and Ernie Harvey of Victor. It took 51 skilled mason man-days and 45 days of unskilled work (myself and another hod-carrier) to complete the wall, furnace and fireplace, (but only about 8 feet of chimney). The original plan was for a cement wall, but a concrete engineer informed me that the wall would break up under the heat of the furnace. I was fortunate to find individuals who could do the solid (not just face) stone work necessary. Laying ceramic tile flue liner through the wall was a real chore. The work was stopped in November by heavy snow.

The following spring I completed the chimney (about 30 days in June and July 1978). About this time I happened to find some beautiful salvage beams in Butte, and revised the house plans in order to utilize this wood to its full advantage. For the next two years (to June 1980), I worked alone doing post and beam framing and construction of the rest of the house. It was too dangerous for help, too distracting, and I was out of money.

In July 1980 I spent about 10 days (plus hod-carrier helping) building another chimney on the East end of the wall. The original plan (Exhibit 2) for a triple wall metal chimney was discarded for reasons of aesthetics and impermanence. In August 1980 the South-facing wall was installed. The original plan was to use custom manufactured thermopane in a 8 x 40 or 320 ft^2 South wall plus a 6 x 32 or 192 ft^2 clerestory. In the interim I was able to find 46" x 76" thermopane reject patio door blanks. These are tempered glass and make for a much stronger installation. By using two teirs of these in a single 12' by 40' wall, I was able to simplify construction and still get the direct gain and daylighting (like a clerestory) over the Trombe wall. In addition this design allowed me to space the glass sufficiently to use the area between the Trombe wall and the glass as a narrow (4 foot wide) attatched greenhouse in the spring and fall. I spent about 10 days (plus two laborers) building a low stone wall on the South to support the glass. Framing the glass with 4 x 6 took me several days and three of us installed and caulked the glass in one day.

As mentioned, the solar hot water collector panel was built in 1977, using a design from a Western Energy Show workshop. Water at the site is gravity-fed from a nearby spring. In order to avoid problems with freezing, I run it as an April to October system. The collector is used in a simple thermosiphon set-up for summer showers. In the heating season, water is heated directly on the furnace. This simplification comes from tent living - discovering what was necessary. The night insulation for the system is 1" Thermax cut to fit the 4 x 6 framing. This double foil-sided insulator is R-8, plus R-2 for a 3½" air space to the glass.

3. System Testing and Modification

The Trombe wall and direct gain aspect of the system are a simple and proven technology. However, having the furnace built into the wall with a 25 foot nearly horizontal flue was an experiment. The main question was how well the furnace would heat the wall and whether it would draw without a mechanical blower. The first time the furnace was lit, in late October, the house had just been closed in and the wall temperature was below freezing. It was necessary to prime the furnace with newspaper lit in the East chimney, and there was substantial condensation in the flue (water and steam actually leaked through the masonry). However, since that time the flue has worked very well. Even when not stoked for three or four days it draws very well on first lighting. The heat from the wall is very pleasant radiant energy and one hot firing has allowed us to coast for several days even in cold weather, as the heat storage calculations suggested. It is a real pleasure to go down in the morning and feel the stone on the East end, stone still hot from the previous days fire, 25 feet away. Due to the high combustion temperature it appears that cresote buildup will not be a problem. There have been no major modifications to date to the system as installed.

4. System Performance

There is no formal performance data on the system as yet (see IV below.) However, the furnace is working efficiently and well as described above.

5. System Cost

Exhibit 5 provides a summary of the System Cost. Out of pocket expenses were $14,373, of which $9,640 was covered by the grant. In addition I put in 108 working days on the various aspects of the project: if my time was $3/hr (or $10/hr?) this would be an additional $2,592 (or $8,640?) if hired out. Realistically I probably also put in an additional month of design/planning and grant-writing time.

The main deviation of real expenses from the grant estimates are for the Trombe wall system (Exhibit 5). Instead of simply pouring a wall out of cement, it was necessary to carefully build it from stone. This approximately doubled expenses for this category from $4,318 to $8,365. On the other hand, the South wall in my home is a massive and very beautiful piece of stone work, instead of a cement slab! I personally think the aesthetics are worth it.

The other major cost overrun is roof, wall, and floor insulation

EXHIBIT 5

SYSTEM COST

	Out of Pocket Cost	My time	Grant
Trombe wall, Furnace, Fireplace			
Excavation	360	5 days	100
Cement work	1173	7 days	1500
Rock transportation	758	10 days	400
Materials (cement, flue liner, Trombe, steel, etc.)	1937		420
Mason's labor	4137	21 days	1898
	$8,365	43 days	4,319
Chimneys			
East (labor $280)	380	12 days	249
West (no labor)	200	20 days	152
	$580	32 days	401
South wall			
Glass	1285		1531
Framing other materials	680		934
Labor - masonary	560	10 days	
framing	384	5 days	330
	$2,909	15 days	2,795

	Cost	My time	Grant
Night Curtains for South wall			
Materials	289		508
Labor		2 days	90
	$289	2 days	598
Other Night curtains	180	3 days	349
Other Insulation			
Labor	256	4 days	
Tower and floor	459		65
Roof	756		199
Walls	301		94
	1,772		358
Solar hot water	278	3 days	521
Administrative		6 days	300
TOTAL	$14,373	108 days	$9,640

(\$1,772 actual vs \$358 projected). In the time since writing the original grant, the house evolved from a compact 800 ft^2 home to a multi-storied home/workshop/art center. The lower main floor is now about 1200 ft^2 (40 x 30) and will be left open for a large wood sculpture workshop and for square dances, theatre, art exhibits, etc. Using the idea of thermal zone, these activities will be appropriate for the coolest area of the house. The main living area is about 700 ft^2 on the second level. In addition there is a large tower on the West for music/theatre/dance performances in the natural amphitheatre found by the hill to the South.

In the very coldest weather, I have been living in the top tower room (120 ft^2) which is a self-contained single direct gain passive unit, well-insulated for warmth and privacy from the rest of the house. It is basically the simple living unit I developed while living in the tent.

6. Economic Evaluation

In this section the cost allowable to each element of the project is compared to the value of the fossil fuel-derived energy saved.

Based on Exhibit 5, the total out of pocket cost of the furnace, fireplace, Trombe wall, chimneys, and South glass is \$11,354. Of this I would exclude \$1,533 for foundation, which would be built in any case. I estimate that of the remaining, \$2,862 went to building the furnace, fireplace and chimneys, and \$7,459 to the passive solar system itself. The Trombe wall and direct gain above it serve structural puposes by replacing approximately 600 ft^2 of wall on the South that would have been built in any case. The value of this structure is about

$50 per 4 x 8 unit or $940. The net cost of the Solar System is therefore about $6,520 (Exhibit 6). Based on Exhibit 4, the system should yield 41.3 million BTU/year of rent comparable in safety and convenience to electricity.

What is needed next is the cost of providing 41.3 million BTU of electricity per year for say the next 30 years to compare to the $6,520 cost of the wall. Electricity now costs 2.4654¢/kwhw or $7.80 per million BTU delivered at 93% efficiency (resistance heating) or $322.14 per year for 41.3 million BTU. To get the present value of 30 years of $322.14 per year, one needs to discount future avoided electric bills at the real interest cost of home financing. Between 1970 and 1979 the effective rate of conventional new home loans averaged 8.77% for the U. S. while the real value of the dollar (used to pay the loans) deflated at 7.22% per year. (Western Economic Indicators, Federal Reserve Board of San Francisco, 1980). This suggests that the real cost of home financing in the last decade was about 1.5%. Current mortgage rate of around 16% are still only + 2 % over 14% inflation. One need also to include real increases in the cost of electricity (over and above inflation); this is likely to be 2.0% to 2.5% annually. Conservatively, if one escalates future electric bills at only 1.5% and discounts them at the same rate, the present value of the electric bill avoided is merely 30 times 322.14 or $9,664 (Exhibit 6). This ignores federal tax deductions but also taxes and maintenance, which are likely to be negligable compared to first costs. The analysis suggests a payback of 20 years. If the fuel replaced is wood at $50 a cord ($5.00 per million BTU at 50% efficiency), the same assumptions

EXHIBIT 6

ECONOMIC EVALUATION

Item	Allocated lost ($)	Million BTU/yr provided	($) Present value of Energy Saved or Provided over 30 years Compared to:	
			Wood at $50/cord	Electricity at 2.46¢/kwhr
Trombe wall and glass	6,520	41.3	6,195 *(32)	9,664 *(20)
Wood furnace	931	39.2	?	
Night curtains	469	31.5	4,725 (3)	7,371 (2)
Insulation	1,772	335.0	$50,250 (2)	78,390 (1)
Solar and Wood hot water	278	2.0	300 (28)	468 (18)
TOTAL COST	$ 9,970	449.0	$67,350 (5)	$105,066 (3)

* Payback in years

suggest a 30 year present value of $6,195 and a payback of 32 years.

The furnace, fireplace, and chimneys cost $2,862. Probably half this is fireplace and half furnace ($1,431). The fireplace probably stands on its own in terms of aesthetics and resale value. The top of the furnace is designed to provide a brick walled cooking oven and steel grill that is worth at least the going price of a good wood cook stove of $500. The remaining furnace and flue cost is about $931. This is more than a large cast iron stove, but the furnace should be much more convenient (with infrequent stoking) and burn much cleaner. The most generous assumption is that furnace BTU's will be qualitatively similar to electricity BTU's. In this case the 39.2 million BTU's could be valued at the extra cost of electricity over wood ($7.80 minus $5.00 or $2.80). This is crude, but suggests a value of $109 per year to the relative convenience and cleanliness of the furnace.

Based on Exhibit 3, the night curtains save 63 million BTU/year if in constant use. Presuming they are on half the time in the heating season, they save 31.5 million BTU/year for $469. This results in a very fast payback of two to three years.

Insulation costs were $1,772 and save 335 million BTU or the equivalent of about 35 cords of wood burned at 50% efficiency! The payback is one year.

Assuming that the solar hot water is used to heat 15 gallons/day April through October, from 40° F to 110° F, this is about 2 million BTU/yr. The cost was $278, for a payback of 18 to 28 years (Exhibit 6). A total evaluation (though adding apples and oranges) suggest a payback

3 to 5 years. The conclusion is that every element of the project appears to be economically feasible.

What is not apparent from this analysis (based on total cost and total savings) is whether the system is optimally designed, or well balanced. For example, since the insulation payback is so fast, why not go from 12 inches to 18 inches? This would require looking at the relative savings of small increases in the scale of each option (another inch of insulation vs an extra ft^2 of South wall). Work I have done elsewhere suggest that this house is roughly balanced ("Toward Planet Terrarium: A Household Production Function for Solar Energy" presented at Western Economics Association Meeting, Anaheim, June 23, 1977).

The preceding discussion did not include any value for my own time (Exhibit 5). This is a crude but perhaps roughly accurate way of excluding two types of costs: pure learning expenses, and those costs that relate primarily to aesthetics as opposed to function (i.e., a 37 foot chimney for the West tower).

On the other hand, there is no benefit calculated to the greenhouse aspect of the system, which I expect to add at least 100 days to my growing season. In addition, implicitly the house and tons of stonework self-destruct in the year 2010, 30 years from now. In fact, the added resale value of the house alone would justify the project expenditure. The median purchase price of homes in the Western U. S. increased 12.2% a year or 5.2% a year above inflation between 1970 and 1979. Assuming constant quality, and using the real cost of home financing in this period (1.5%), this suggests that my Trombe wall is a good investment (not an expense) yielding @3.7% real return (over and above inflation)!

It should also be noted that for some questions, such as public support of solar energy, it is more appropriate to look at the full social cost of fossil fuel alternatives. For example, when the federal subsidies, replacement cost and some externalities are included,electricity in Montana is really costing society more like $20.76 per million BTU (as opposed to the $7.80 market price.) This provides a fairer comparison to solar. I have attached a reprint of a recent paper I wrote on this issue("Solar Economics and Ethics").

The only area in the project with potential cost savings are the wall itself. Solid stone work is relatively slow and expensive. Most commercial builders of Trombe walls and direct gain are going with cement block filled with sand or concrete and sheetrocked on the interior. However, this precludes use of a hot flue through the mass. Perhaps structural steel with loose rock would be a possibility? Or we should look at the 9 ton Russian stoves and the tile or brick stoves of western Europe.

III. Conclusions and Recommendations

I feel that the significance of the project is the integrating of the wood backup into the Trombe wall mass. In the Missoula valley, most residents burn wood in stoves that use draft controls to control heat output. Cutting the draft results in incomplete combustion and during inversions can markedly affect air quality and human health. On the other hand, most new houses are built with electric baseboard heat - causing strip mining pollution in Colstrip, instead of here. I feel that intelligent use of thermal mass with wood will allow good hot complete combustion when the air quality is good, and a way of coasting through inversions with no fires at all. Meanwhile, using the solar we do have (even in a limited site like my own), can greatly limit our use of Montana coal. While I am anxious to evaluate and gather data on my own place, I feel the real need is to develop a simple retrofit technology for getting thermal mass on existing wood-burning units.

IV. Monitoring

For the long term, I am hoping to get Charless Fowlkes to monitor my project. My immediate curiosity is directed toward finding someone to analyze my flue gases to test the "complete combustion" hypotheses. In January I plan to keep a careful record of wood burned and temperatures in order to establish my actual heat load. Then, in February and March, I will go completely on solar for a time and (based on heat load) evaluate that aspect of the system. Temperature recordings and sunlight data will be the raw information. I am also planning to experiment with various loading rates and firing intervals with the furnace to begin to understand the thermodynamics of the flue gas/rock/room air heat transfer. I would like to use temperature probs to plot the heat pulse through the wall.

V. Public Availability

To date probably 150 people have seen the project, most of them locals who know by word of mouth. The site is relatively secluded; the nearest parking is about a half mile from the house. Winter access is particularly difficult. I generally travel back and forth to town (5 miles) by foot or bike or skis, and I strongly encourage visitors to do likewise. Even if all visitors were from the Missoula area, the average trip by car uses about a gallon of gas. At this rate 270 visitors per year would totally wipe out any fossil fuel savings attributable to the project. I have no phone, but during winter and spring can be easily reached at the Economics Department office 243-2925. I am also open to speaking on the project to interested groups. I enclose a copy of a paper I recently presented at the 5th National Passive Solar Conference in Amherst, Massachusetts; the paper was in the "Emerging Architecture" session and (with slides) describes the design/construction experiences of this project.

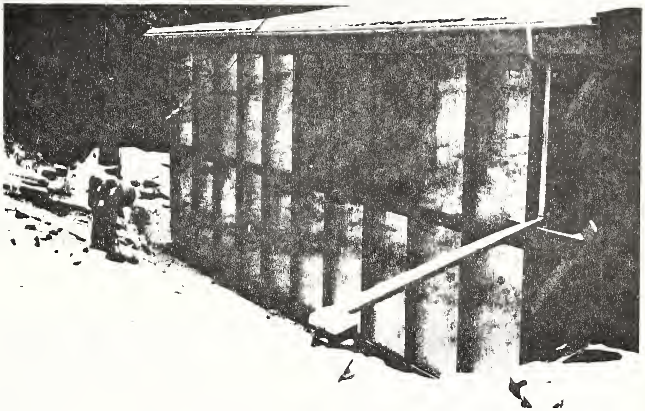
VI. Program Evaluation

My own economic research has strongly convinced me of the need for renewable energy demonstration projects. In general, I am very pleased with the direction the Montana DNRC has taken. One small suggestion: my own experience is that a uniform one year deadline on completion is sometimes unrealistic. I feel that the Montana DNRC should encourage grass roots inventiveness and experimentation. Unless an individual is willing and able to turn to established construction personnel and techniques, a serious scale project is going to take some time. Meanwhile, I have appreciate the patience shown toward my own efforts during this interesting and lengthy learning process.

Attachments:

"Solar Economics and Ethics"

"Passive Solar Meets North Slope Rockies"



South-facing Window Wall

Trombe Wall, Furnace and Fireplace

Fireplace

Furnace

Furnace and Oven

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PASSIVE SOLAR: ECONOMICS AND ETHICS

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ABSTRACT

This paper examines the economic feasibility of passive solar for space heating. The key finding is that from the standpoint of society the costs of substitutes have been badly understated. The major source of error is valuing at average rather than replacement costs, using steady state furnace efficiences, and failing to adjust for government subsidies in the production of fossil fuels. This provides a basis for explaining the failure of the market and individual choice. The last part of this paper briefly explores the issue of corrective policy from the standpoint of efficiency and ethical criteria.

1. INTRODUCTION

This paper provides an analysis of the potential for using passive solar energy for residential space heating. The main questions being addressed are: (1) Does the use of passive solar for home heating make sense: and (2) If it does, why aren't we using it?

To ask whether something "makes sense" implies some criteria or basis of evaluation. Conceivably, people could design and build houses to satisfy an ethic, such as the belief that we should minimize our impact on the natural world or the belief that we should be dependent on and live in close harmony with the natural forces on this earth. For better or worse, sun worshippers appear to be as scarce in Montana as they are in the rest of the nation. Instead, a materialistic motivation appears to be a more powerful explanation. This mundane line of reasoning leads to the specific question examined here: Has passive solar energy become the least costly way to heat houses?

2. SOLAR COSTS COMPARED TO ALTERNATIVE FUELS

The quick answer is that it depends, it depends on how well the solar system converts sunlight into usable heat, how much the system costs, the alternatives available and their costs, and on a number of site-specific parameters such as the amount of sunlight available over the course of the year, the severity of the climate, and the thermal characteristics of the building itself. These can be only briefly discussed in the following sections. For purposes of illustration here, two Montana extremes will be examined: Missoula and Glasgow. Glasgow is one of the best solar sites in the world. It has a cold winter climate with approximately 62 percent of possible sunlight over a six-month heating season. By comparison, Missoula is warm and gloomy--with only half the Glasgow sun (37 percent average) and about 15 percent lower heating needs.

The specific system examined here is a 46 cm (18 inch) thick concrete trombe wall with an R9 night insulating curtain. The physical relationship between sunlight at the site and useful solar energy supplied is identified by the solar load ratio method developed at the Los Alamos Scientific Laboratory (LASL) (1, 2, 3). For economic analysis, the LASL production function has been integrated into a larger computer simulation model, SUN.PAS developed by the author and others at the University of Montana. Space does not permit a fuller description of methodology (4). In the runs reported here, the prototype building is a well-insulated 13MJ/m^2-C^o degree day. (6.4 BTU/ft^2-F^o degree day) 139m^2 (1500 ft^2) house.

The cost per square foot of the passive system will depend on the choice of storage medium, venting, glazing, the type and quality of insulating curtain, the cost of the convential south wall replaced, whether resale value is a credit and on the frugality, experience, and inventiveness of the contractor or owner/builder. For example, carefully delineated costs for two roughly similar trombe systems were reported in the 4th National Passive Solar proceedings. Both of these used cement block filled with concrete, but one cost \$102/m^2 (\$9.50/ft^2) (5) and the other cost \$298/m^2 (\$27.15/ft^2) (6). On the other extreme, my own experience is that an intricate solid stone wall (medeival/monolithic) may cost \$400/m^2 (7). While the average number without resale may be around \$17 to \$20 per square foot of system in 1980 dollars, passive system costs are highly variable (8).

In order to identify if solar is cost-competative, it is also necessary to know the cost of the alternatives. In Table I the August, 1980, delivered cost of energy to the individual Montana homeowner is derived.

TABLE I

May 1980 Montana Energy Prices

Fuel	\$/Physical Unit	¢/KWhr rate	Furnace Efficiency	¢/KWhr delivered
#2 Fuel Oil	98.4¢/gal	2.39	.65	3.68
Natural Gas	3.448\$/mcf	1.19	.75	1.56
Wood	50 \$/cord	.85	.60	1.42
Electric:				
Resistance	2.4654¢/KWhr	2.47	.93	2.65
Heat pump	2.4654¢/KWhr	2.47	1.34	5.41

TABLE II

Thirty Year Annualized Montana Energy Prices (May 1980 dollars, 11% discount rate)

Fuel	Annual/real escalation rate (%)	Cost to the Individual (¢/KWhr)	Cost to Society (¢/KWhr)
#2 Fuel Oil	.02	5.75	9.50
Natural Gas	.075 to 1990 .02 thereafter	2.29	4.23
Wood	.02	2.01	2.01
Electric			
Resistance	.022	3.17	7.06
Heat pump	.022	2.20	4.90

These Table I numbers are the prices most likely to be referred to in the owner/builder's evaluation of the potential savings of passive solar systems. However, these values are in fact bad underestimates, and their use incorrectly biases decisions against solar. There are two necessary corrections. Instead of using full-load combustion efficiency (for example, .65 for oil furnances), a more appropriate measure is seasonal preformance efficiency which tends to be substantially lower (.492 is one finding for fuel oil (9)). Real fuel costs to the individual are also underestimated if rising costs (over an assumed 30 year life of the solar system) are ignored. The combined effect of projected real fuel cost escalation for Montana and seasonal efficiency are reported in Table II.

The point of this is that the owner or builder may not be choosing solar even if it is in his own best interest. In Figure I the average and marginal cost of passive solar heat in Missoula is plotted for a 215\$/m^2 (\$20/ft^2) trombe wall system, a 4% discount rate, and over a 30 year life cycle. While passive solar energy under these conditions is more expensive than electric resistance heat at 2.65¢/KWhr (Table I), it is cheaper than the likely actual cost (including projected real fuel escalation) of 3.17¢. In fact over 90% of the new units being built in Missoula are installing electric resistance heating.

Unfortunately, when a new house is plugged into the Montana Power system, the customer doesn't face the full social cost of this new power. Electric rates faced by individuals are based on average utility costs, including very cheap power from existing hydroelectric plants. The incremental energy required to meet added loads is coming from new coal-fired steam plants such as the twin 700MW Colstrip plants now being built in South-Central Montana. The cost of this new energy is estimated to be 7.06¢/KWhr, or about 3 times the average rate faced by Montana customers. (Table II) (Space does not permit a discussion of the derivations of this estimate) (10, 11, 12, 13). Besides the divergence caused by average rather than long-run marginal cost pricing, conventional fuels are also subsidized by federal tax benefits such as the percentage depletion allowance. Brannon (14) has estimated that fuel oil and natural gas prices would be 12.9% and 11.7% higher respectively without this federal subsidy. This correction is also incorporated in Table II. Finally, the negative impact of conventional fuels on the environment and on human health is not fully reflected in the price we pay. In one attempt at identifying the unpaid cost of electric energy, Ramsey (15) concluded that uncompensated air pollution damage to health, crop and property averaged about 5.3% of U.S. electric rates.

3. ECONOMIC FEASIBILITY OF PASSIVE SOLAR

For evaluating public policy toward solar energy, the appropriate basis of comparison is the cost to society, not to the individual. The estimates of the former summarized in Table II are conservative underestimates. Nonetheless, the findings reported here suggest that the true social costs of using fuel oil, natural gas, and electric heat In Montana are approximately three times higher than their current market prices. Reference to Figure I indicates that for $\$215/\mathrm{m}^2$ ($\$20/\mathrm{ft}^2$) system at 4% discount rate, passive solar heat is avilable at 3¢ to 4¢/KWhr, even in the relatively unfavorable solar site of Missoula. This is still half the true social cost of electric resistance and fuel oil and is even competative with natural gas. In a favorable site such as Glasgow, solar energy average costs are more like 2¢ to 3¢/KWhr at a 4% discount rate.

Given the range of costs for alternative passive system construction materials and methods (reported above), an alternative approach is to solve for the breakeven passive system cost per square meter given the known fuel price. Figure 11 provides this information as a function of system size. The discount rate used for this case is 11%. Based on Figure 11, even passive systems costing only $100\$/\mathrm{m}^2$ (about $\$10/\mathrm{ft}^2$) would not be feasible against 2.65¢/KWhr electricity. However, when compared to the estimated social cost of electric at 7.06¢, passive systems costing $215\$/\mathrm{m}^2$ to $270\$/\mathrm{m}^2$ ($\$20$ to $25/\mathrm{ft}^2$) are competative, even using a rather high real discount rate of 11%.

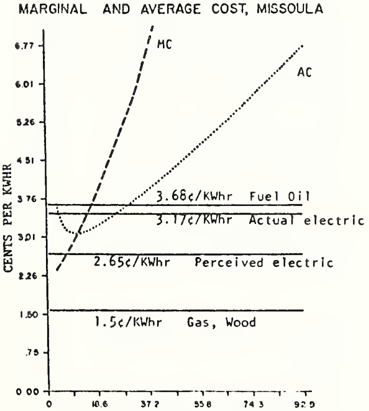

Fig. 1. This graph illustrates the average cost and marginal cost of passive solar heat in Missoula as a function of glazed area for \$215 per square meter ($\$20/\mathrm{ft}^2$) of system cost vs. the cost of various auxiliary energy sources.

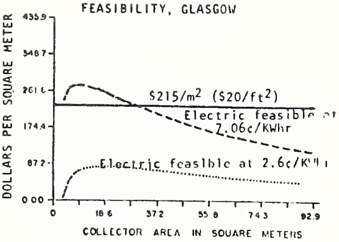

Fig. 11. This graph illustrates the economically Feasible (breakeven) passive system costs per square meter of glazed area for 2.65 and 7.06 cents per Kilowatt hour auxiliary fuel, 11% real discount rate in Glasgow, Montana.

Space does not permit a full discussion of the Issue of feasibility: the appropriate life cycle, the pay back period, the discount rate, optimal system size, and the sensitivity of results to alternative sites and systems across the U.S. Nonetheless, the conclusion here is that on economic grounds that there is a very strong case for the use of passive solar in home heating. Additionally, given the divergence between private and social costs, a vigorous public policy is necessary and justified.

4. ETHICS

The preceding discussion presupposes an efficiency-type criteria: people will (and should) prefer the least costly alternatives. Economists would not employ this behaviorial assumption so exclusively (it is really somewhat insulting) if it wasn't so successful in explaining American society. The price of hamburger goes up and the price of chicken goes down: three guesses on what will happen. When the price of hamburger goes way up, we have what is called a hamburger crisis as (cut off from their main source of energy) everyone goes into shock learning about vegetables and walking, and...shades of occult mysticism: the sun itself. A country that runs on hamberger can not afford to run short.

Nonetheless, there appears to be an increasing lunatic fringe operating on a contrary principle--that less is more. The environmental movement, for example, appears to be largely ethically motivated: the belief that we should minimize our impact on the earth, that other species (such as the grizzly) have the right to survive on this planet. At present, the only ethical points being strongly raised in the energy debate are coming from an older culture, one which our more-is-more culture attempted to exterminate. In Montana new energy is coming from coal and more hydro. Both are being opposed by Native Americans on ethical grounds. For example, in a recent discussion of a proposed hydro-electric project at Kootenai Falls in N.W. Montana, Pat Lefthand of the Kootenai Tribe said the dam would destroy the religious signficance of the cascades for the Tribe: "We didn't pick the site. The spirits picked the site for us. The Supreme Being does not guarantee an alternative site." (16). Similarly coal developments and transmission corridors have been major cources of conflict on the Flathead, Crow, and Northern Cheyenne reservations. In the Southwest U.S., Native Americans have been arrested for physically opposing coal mining that is destroying ancestral graves. As Aldo Leopold cogently argued long ago (17) (and the late William O. Douglas more recently), we have no ethic with regard to the land and its resources.

Besides simply stating that ethical beliefs are a viable alternative basis of choice to economic efficiency, it is important to understand that economic analysis presupposes certain essentially ethical assumptions. For example, a key question is who are the beneficiaries of a given choice--such as to build a passive system, or a dam, or a coal mine. Current analysis rests on the essentially moral choice that decisions are from the standpoint of the living humans directly impacted. An alternative is to expand the frame of the analysis to include the future, or other species (the grizzly) or even the past (ancestral graves).

5. CONCLUSIONS

When the full social costs of fossil fuel-based energy are identified, passive solar is found to be economically feasible for a wide range of sites and construction methods. If this economic analysis is modified on ethical grounds to take better account of future and non-human populations, the results are only strengthened. This is, of course, due to the relatively benign nature of solar energy as compared to fossil fuel conversion. Given that our market system is incorrectly signaling energy using choices, a major public program to encourage/subsidize the use of solar energy is justified. Perhaps the most exciting aspect of the passive solar movement is the possibility of redefining our society's idea of shelter: from one of simply "warm space" to shelter as the basis of a self-sufficent life style that is in harmony with our source of existence on this earth. Does this sound like sun-worship?

6. ACKNOWLEDGEMENTS

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7. REFERENCES

(1) Balcomb, J.D., and McFarland, R.D., "A Simple Empirical Method for Estimating the Performance of a Passive Solar Heated Building of the Thermal Storage Wall Type.", Presented at the 2nd National Passive Solar Conference, Philadelphia, March, 1978.

(2) Wray, W.O., etal, "A Semi-Empirical Method for Estimating the Performance of Direct Gain Passive Solar Heated Buildings.", Presented at the 3rd National Passive Solar Conference, San Jose, January, 1979.

(3) Wray, W.O., and Balcomb, J.D., "Trombe Wall vs. Direct Gain," 3rd National Passive Solar Conference, San Jose, January, 1979.

(4) Duffield, J., 1979, "Solar Energy and Market Failure," Conference proceedings, Technology for Energy Conservation, Tucson, January 22-25, 1979.

(5) Naumann, R., "A Builders Experience with Two Passive Solar Houses in Boulder, Colorado," Presented at the 4th National Passive Solar Conference, Kansas City, October, 1979.

(6) Sullivan, P., "An Analysis of Incremental Construction Costs of Passive Solar Buildings," Presented at the 4th National Passive Solar Conference, Kansas City, October, 1979.

(7) Duffield, J., "Passive Solar Meets North Slope Rockies," Presented at the 5th National Passive Solar Conference, Amherst, October, 1980.

(8) Noll, S., 3rd National Passive Solar Conference, San Jose, January, 1979.

(9) Office of Technology Assessment, *Residential Energy Conservation*, United States Congress, March, 1979.

(10) *Electrical World*, 1980 Annual Statistical Report, March 15, 1980.

(11) "Energy Modeling Forum," *Coal in Transition*, EMF Report #2, September, 1978.

(12) Duffield, J., "Future Prices of Electricity," 1977, The Montana Energy Advisory Council.

(13) Federal Energy Regulatory Commission, Hydro-electric Power Plant Values, July 1, 1979.

(14) Brannon, Gerald, *Energy Taxes and Subsidies*, Ballinger, 1974.

(15) Ramsay, W., *Unpaid Costs of Electrical Energy*, Johns Hopkins, 1979.

(16) "Packed House Discusses Kootenai Falls Project," *The Missoulian*, July 30, 1980.

(17) Leopold, Aldo, "The Conservation Ethic," *Journal of Forestry*, October, 1933.

(18) Douglas, W.O., *A Wilderness Bill of Rights*, Little Brown Co., Boston, 1965.

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PASSIVE SOLAR MEETS NORTH SLOPE ROCKIES

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ABSTRACT

This paper describes the origin and construction of a passive solar home near Missoula, Montana. Due to the owner/builder's direct descent from Nordic trolls, the site is a relatively cold and wet north slope huckleberry/larch habitat. The key element of the design is integration of a wood furnace/fireplace/oven into a massive trombe wall. The construction has been largely a sculptural experience in the sense that the design has emerged from an on-going interaction of the builder, site, and materials.

1. INTRODUCTION

The theme here is a simple one: home is more than a warm space. For the last several years, I have been carving a home that is a mask big enough to live in. This approach to shelter is sculptural; specifically--it is primitive art. Not only in the sense that it amounts to chopping on dead trees and piling stone on stone, but also as a celebration of nature and man through simple and direct symbols. For me, it is an exploration of my connection with the natural world--a rooted connection on a particular north slope of the Sapphire Mountains. I feel I have learned a great deal through my passive solar project--and there is near the heart of it BTU's, dollars, and perhaps even one or two well-calculated vectors. However, my intent here is to balance the well-directed focus of the passive solar movement on these latter considerations with a brief exploration of some other dimensions. Perhaps this is most possibly communicated by the imagery itself--photos of the physical plane visuals.

In this paper I will see what can be done with words. Be forewarned that I am trying to mine a different essence here: the image, the idea, like keys to some closed door--perhaps between man and nature, man and himself, spirit. To feel right I like to be harvesting and conscious of these elusive flashes and hints. Carvings and poems seem to be as close as I come.

The Ceremony of Timbers I/August '80

Slowly the work deck
is disappearing into the sky--
some say scaffolding for the roof,
others say: three years,
too short a time to frame a house.

Day by day
appear the long-covered floor girts,
the fir 12x12's
worked to a fine cure:
forty years on a tressle in Buttle.
Now they rest,
no ore cars here--
bare feet, a chair.

And beneath the revealed beams,
three summers of sawdust and shavings
and plane curls and anger spirals
and adz chips in an incredible
undoable jigsaw puzzle.

Its mirror image,
the puzzle in the sky--
my mortise and tenon puzzle
rising from the sawdust,
not unlike the puzzle of pine bark
at the base of a growing tree.

I don't know whether to start with woodcarving or ice cream making. Both are primarily experience rather than static material possessions; but they do involve tangible three dimensional forms--the curve of a bird's wing or the texture of freshly frozen berries and cream. Perhaps the start should be in the picking which precedes both.

2. PICKING

The first problem in building a home is choosing a place; this is the nomadic phase. Exploring, mostly on foot and bicycle, for ten years, I finally located the general area (Missoula, Montana), and began to make increasingly intense forays from a home base. Almost every afternoon, my bike was inexplicably drawn to a small canyon to the east. A major consideration was to be only a self-propelled distance from work/urban culture. One day in May I went to actually look at land for sale. The huckleberries were in blossom on the place, I accidently treed a bear, and the owners turned out to be named Bliss. Riding down that evening for the thousandth time on my trustworthy bike, I hit the same old bump going perhaps 30 mph hard downhill bareback (my toes strapped in). The front fork broke and sent me into emergency. Later, swathed in an entire mummy of bandages, eighteen stitches over my left eye, I took it as a sign to stop traveling and set roots.

The homestead phase began in July, 1976, after climbing in the Mission Mountains over the fourth. Like the real cowboys in the mountains, I was wearing a CENEX hat, and somehow realized--after catching a trout barehanded in Summit Creek--that independence had not yet been declared. The CENEX patch was cut off and replaced with a small memorial fish carved out of a spruce splinter; this winter's blowdown--very strong light wood already dried in the summer sun. This is where part three starts about woodcarving.

3. WOODCARVING

When I moved out of town, driven by dogs and drawn by huckleberries--there was a house defusing ceremony. Friends came and took the sacred objects into their own keeping. Where I was going wasn't safe for them. The next day I moved up and pitched my tent. Home was fifty acres: steep mountain terrain, bordered by National Forest, 18 reckless minutes on the bike to the Top Hat Bar (over the bump again), forty minutes home (maybe). I lived the winter in an old 14x16 outfitter's tent given me by my father. My idea was a good workshop and a place to lie and sleep and a corner to cook in. Unplugged from the electric culture, there were the beginnings of homemade music. One evening I went up and formally staked out a site: by playing an old English tune learned on my wooden recorder--Three Ravens. Tentative piling holes were dug, but the ground froze before I finished, and the larch needles rained down on me, yellow like Vermont birch. That winter, after hearing about a state solar grant program, I designed a trombe wall with a stone furnace built into it. This system seemed to make sense for the north slope I already called home, and was perhaps a new idea in 1977. As it turned out, the grant only paid my education as a stone mason--hod carrier and mixer of mud, and perhaps one stone that I paid in a 40 foot wall.

With no money, for the next two years I worked alone. To keep my focus on the workshop, I had sworn off carving when I moved out. It turned out that this made me channel any artistic energy into the building. In part, it has been a sculptural experience in the sense that the materials are very unique and individual. Before the cutting began, I reluctantly but intuitively learned the general character: skew, straightness, twist, bured spikes, color of each of about forty 12x12 and 10x18 beams--32 feet long, Douglas fir.

My father had spotted salvage work on Montana Street in Butte and put me on to it--I bought a semi-load after long negotiations. There were major design changes almost daily--as necessary each section of the house got attention--independent, then wholistic. For example, the chimney was unfinished when the grant ran out, so I gave it a try--a ton of stone every foot, picked the August before on a scree slope just over the ridge. At 23 tons (early June, 1978), the idea occurred to make the chimney a pillar on a tower, so the full length of the beams could be used. The Three Raven seed sprouted a Three Raven tower drawing: raven heads on three of the top corners--and a chimney in the forth. Part of the motivation was the idea for a flat topped tower dance/music stage for the huckleberry amphitheater (meanwhile--the workshop?). This was such a major choice that the I Ching was consulted: "Stagnation, August, September time-period", it said (In other words, trouble). Despite the forewarning, that's what I chose and got--a 37 foot chimney and a few floor joists to lay in the winter snow.

The next year the mortice and tenon tower joints took 90 days before the August raising of the tower--an almost incomprehensible puzzle. The tower was probably the major design interaction/change but the new images kept coming. One night, while looking at the drawings, log diagonals grew claws and the roof line North became a wing: the tower turned into an owl. And just then an owl sounded up the hill--a male Great Horned (by its four booming notes). The raven heads had turned into ears--like on the Great Horned. Later details occurred at the odd moment: breast feather shingles of pine/larch mixed to grey into a barred breast, pine board wing feathers over an open porch to bring out the wing. Many hours were spent just looking and imagining. The height of the tower was set by the beams, but the cross-section, 14'x14', is in honor of a beautiful wool braided rug that has come down from my Norwegian grandmother. Long ago my other grandmother, who homesteaded near Fort Benton, gave me a buffalo horn. It has been set with a quartz skull (found on Lolo Peak) into the N.E. stone pier on the foundation, the "ancesteral pier." These are roots.

Last November, just before the snows closed the old skid road to Camp Two, I moved into the top of the tower: "beyond the wool door--a ladder up the chimney." It had been over three years, a lot of snow, a lot of huckleberries, and a lot of dark nights learning the fiddle by the fire. The idea is an old one: get to the basics and find your needs, satisfy them in direct and simple ways The major harvest from that time was a simple lesson: self-reliance (perhaps an image for the future).

Tenting on Old Lake Missoula

For three years
I raised the canvas
from my deck,
and set sail
on the white ocean of winter.
I bowed to the North Wind,
I rose and fell
with the mountain tide.

Exploring the waters
of my dream life,
always the Sapphire Islands.
And so, I have come
to a mooring
on the shoreline
of an ancient lake.

Invisible waters
lap at my porch,
terrace the hillside,
nourish the wild fruit.
I built here
with the shipwright's eye,
looking to the centuries.
My ark for overwintering,
overturned:
ridgepole, my keel.

And from the crows nest,
view into deep waters.
Atlantis of the Hellgate,
still your crystals gleam.
Light of the passing culture,
age of new ice coming,
turning mountains into islands,
and houses into ships.

The defusing ceremony now looks like a cleansing. There was a need to come unemcumbered and form fresh images from this place. It was frugal, harsh, and necessary. The images are many. I learned to keep my dishes low in bear season--no sacred objects here, bear. Some were treed and tortured with the fiddle. The next morning, little black noses coming in the tent flap. Yellow/black/red tanager in the purple huckleberries--a weasel white too soon--wild roses after a rain--clemantis going to seed--the glacier lily salad mountain spring.

There is also an image connected to the last carving before moving out--"portrait of the artist as a laminated beam." "The key is in the joints" I wrote in my journal then. Good training for this house--long since evolved from workshop to mountain lodge. That carving was also called Passive John--well before the words "passive solar" were current. The idea occurred during a theater/dance workshop doing an exercise called active/passive. One person (eyes closed) is *moved*--another moves. On that Passive John carving everything was completed by the hands. One day, long after, the idea came to set two big larch posts in the house as raw material for giant carved hands (holding the 10"x18" rafters). This was the first actual wood sculpture *per se* idea on the structural members of the place;

it struck me that in this project I was really using my hands, for the first time in my life, and that my solar house is an extension and in a certain sense a completion of myself--Passive John. Perhaps I have built a temple to the hands, a place for hands to celebrate. If there is a message here for others...let there be better use of the hands. I am encouraged to see the recent discovery of the feet that has swept across America to media fanfare and cash registers ringing up Adidas after Adidas. Unfortunately, and symbolic of our incredibly rich and wasteful culture, this exploration of the feet is often indulgent, compulsive, and not efficiently directed. After driving back and forth to work--another drive to the park for a run. Perhaps we could now move on to the hands. Grinding wheat, kneading bread--a simple but major beginning.

Do these references to hands and feet seem somewhat irrelevant? The point is that some modest substitution of lettuce and carrots for gasoline via the human furnace is of the same magnitude of importance as sun for #2 fuel oil. Here is a rough empirical Round Trip Rule: the average solar home built at a car-commute round trip distance greater than your car's miles per gallon efficiency increases net fossil fuel consumption.

4. ICE CREAM MAKING

The hands lead to the fourth part--ice cream making. The night before last I picked huckleberries--several quarts, put them in jars to freeze for winter pie rituals. Then I picked a few more cups. They have been incredible this year, matching the garden in abundance. I mashed the berries in my hands and dropped about three cupfuls into my old Alaska hand-crank freezer ($1.50 at a Vermont Flea market in the nomad days), pint of cream, pint of milk, a little less than half cup of honey, tablespoon vanilla--frozen in about fourteen minutes (Greg timed it on his railroad watch). Incredible almost sherbert in those proportions, but creamy. I was thinking then how the ice cream freezer is to the freezer, refrigerator--as the tent is to my lodge. Going light--and using it when you need it, not plugged in, but portable, or rooted without destroying. Anyway, this fourth section could be a technical discussion of my major engineering choice--thermal mass/insulation. The tent was fine for me--I arrived home hot and sweaty from running or biking or skiing--spring, summer, fall, winter. When it was winter, and sometimes 20 below, it was perhaps a little intense at times. I had to have a fire. But on rising in the morning warm from my sleeping bag, I filled the stove with kindling before immediately going for a morning run--these last years, generally into work. At night, I only needed to be able to hold a match in my cold fingers. With no thermal mass, in moments the tent was warm and the stove pipe as cherry red as anyone could want. Home.

Black Stove

Running home
up the Deer Creek glacier,
I think of you.
Cold and hungry,
squatting on your
short black legs,
waiting to be fed.

The nineteenth century
explodes
inside your iron belly.
Sunlight from that August
so long ago -
hear the rain,
hear the thunder.

Sharing the floor
for our ritual meal,
split larch,
sprouted wheat.
Breathing...
into the fire:
red embers, blood.

On retiring--the stove burned out, and the tent was almost immediately cold--cold enough to be in my down bag, and so I was, and always slept well.

Quite seriously, the main complaint was poor acoustics and a thermal gradient so great that if I stood up while playing the fiddle to move around, I had to retune. To nurture this slow but continuing development of the hands, I am now exploring the other extreme: a large volume of thermal mass---over 180 tons of stonework alone. In place of twelve ounce duck, twelve to twenty inches of fiberglass in the entire roof. My big window faces south. The only major innovation is to use the stone wall mass for wood furnace storage. This largely solves the major problems of wood heating--constant attention and/or draft control resulting in incomplete combustion and air pollution. This is a major problem in the Missoula vally during winter inversions. An 85 ton stone furnace and flue allows one very hot and infrequent firing--the week long ritual of kiln to pizza to bread to unleavened bread to the 24 hour turkey at 150 degrees on Sunday. With a conceptually similar set up in Bozeman, Montana, the severe winter of 1978-79, Charles Fowlkes lit his furnace 16 times. I have since learned of multi-ton Russian stoves and the massive tile/brick stoves of the Pennsylvania Dutch.

This furnace is the price I pay every winter for living in my native habitat. All three of us, larch, huckleberry and me--like the north slope. We leave the parched South to the Ponderosa and grasses. I pay with winter sun for summer huckleberries, and count it a good enough bargain. Yet forty to fifty percent of my annual heating needs will still be satisfied directly by the sun.

The passive solar movement seems to have spawned one major new design element in American residential construction--simply this awareness of thermal mass. Unfortunately, most homes continue to be built for the unknown and fictitious "normal" buyer. At the base of this is our primary image of the home as an investment, as a possession largely described by its resale value. This seems to be the major barrier to any innovation such as solar, let alone any even tentative personal shelter harvest.

The Ceremony of the Timbers III

Now the work just spins off--
the north octagon, a rafter set,
the east face.
Working my way from owl
to rising sun
in a yearly procession.

And at its heart:
the ceremony of timbers,
the old larch post from home
married to a fir stump
from this mountainside.

In this ritual,
forming this abstract tree
and carving its myriad limbs,
I have set down my own roots.

In the last swing
of the red axe,
a small evergreen is felled,
nailed to the ridge.
It is time for the hammer.

5. ACKNOWLEDGEMENT

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